An *In Vitro* Study of Cement Retention as Related to Orthodontics

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Although the bonding of orthodontic brackets directly to the teeth is receiving much current interest, the vast majority of orthodontic appliances are still being cemented using stainless steel bands and conventional dental cements. Surprisingly, the literature reveals little information regarding the retention of orthodontic bands when cemented with various dental cements. Past studies have investigated the chemical composition of various cements, their physical and chemical properties, or their application and use in restorative dentistry.[1-8] Unfortunately, physical properties of dental cements, such as compressive strength or tensile strength, make uncertain predictors of the actual retentive ability of a cement to retain an appliance in place on a tooth.[6,8-10] It has been shown that regardless of cement type, no physical strength property was a good predictor of actual retentive strength.[9] Finally, studies that have appeared in the literature which deal with cement retention were often restricted to the retention of precious metal castings.[6-8]

In one of the few studies involving the retention of orthodontic bands, Williams[10] investigated the relative force necessary to dislodge orthodontic bands from extracted human teeth cemented with various dental cementing agents. Zinc phosphate, silicophosphate, and EBA reinforced zinc oxide-eugenol cements were included. Using solder reinforced bands, he demonstrated that zinc phosphate and silicophosphate cements were similar in their ability to retain orthodontic bands and that the retentive strength of these two cements was slightly more than twice that of the EBA cement. Although this study provided data of interest to the clinical orthodontist, the methodology produced a coefficient of variation of 26%. Further, more meaningful interpretation of the data would have been provided with more sophisticated statistical treatment. Using similar methodology, Houston and Miller[11] also demonstrated that zinc phosphate, silicophosphate, and black copper cement possessed similar retention properties. No statistics, other than over-all mean values, were reported.

Smith[3] described carboxylate cement as the first dental cement which does not rely solely upon irregularities of the adjoining surfaces for mechanical retention. Carboxylate cement is a powder-liquid material, the powder being a modified zinc oxide and the liquid being an aqueous solution of polyacrylic acid. Smith noted the polyacrylic acid molocules have the ability to chemically bond to calcium ions on the calcified enamel tooth surface as well as to stainless steel. However, even though carboxylate cement does achieve a chemical bond with tooth enamel, it has not been shown to be superior to zinc phosphate cement. Physical property studies[4,5] with carboxylate cement have shown it to be clearly inferior to zinc phosphate cement in compressive

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strength and tensile strength. Further, carboxylate cement proved only equal to zinc phosphate cement in solubility, film thickness, setting time, and pH. Carboxylate cement proved to be superior only in adhesive strength.

In an attempt to relate film thickness to retention, Collins[12] evaluated a variety of dental cements using a metal die and collar apparatus. Although some variation existed among the individual cements, no relationship could be established between film thickness variations and band retention.

No reference could be found in the literature concerning red copper cement. However, several orthodontic clinicians subjectively claim superior clinical retention with this cement type. Because of this claim and the frequent clinical use of red copper cement, it seemed worthwhile to investigate this cement type.

Two conclusions became apparent after reviewing the pertinent literature. First, methodology has generally resulted in data with a large coefficient of variation. Second, there are some commonly used orthodontic cements which had not yet been investigated. Therefore, the purpose of the present investigation was twofold: To develop a reliable method for testing the retention of cements used to retain orthodontic bands and to relate the retentive characteristics of zinc phosphate cement to carboxylate and red copper cement, two types of cement not previously investigated.

Methods and Materials

A sample of ten freshly extracted human premolar teeth, six mandibular and four maxillary premolars, were selected for the study. Teeth with any indication of hypoplastic areas, decalcification, fracture lines, or caries were rejected. Each tooth was thoroughly washed and scaled to remove all remnants of the periodontal attachment and embedded in a block of self-curing acrylic up to the cervical line. Each tooth was then fitted with an optimum size seamless contoured orthodontic band. After the bands were placed, an acrylic collar was built around each tooth to conform to the gingival contour of the band. This procedure created a positive stop, so that during subsequent cementations each orthodontic band was seated to the same height occlusogingivally.

Tie buttons were spot welded to the bands to facilitate the attachment of the band to the removal apparatus. These buttons were placed on the facial and lingual surfaces in a position approximately 180 degrees on each side of the band from one another and at the same vertical height (Fig. 1).

The three cements included in this study (Table I) were handled under rigidly standardized conditions. All cement powders were weighed on an analytical balance and the liquids measured with a B-D Tuberculin syringe. Consistency tests for all three types of cements were carried out in

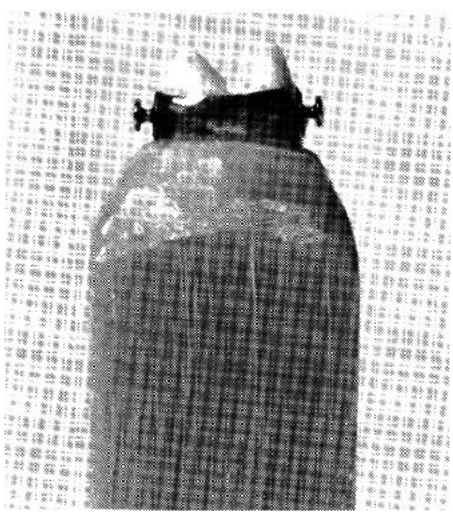

Fig. 1 Premolar mounted in acrylic holding block with orthodontic band in place. Note the locations of the spot welded tie buttons.

TABLE I
Dental cements used in study

Material	*Brand*	*Liquid/ Powder Ratio*
Zinc Phosphate	Fleck's Extraordinary Cement Light Yellow, Batch # C71	0.5cc/1.08g
Carboxylate	Durelon Batch #4507	0.5cc/0.49g
Red Copper	Ames Crown and Bridge Cement Red Copper	0.5cc/1.35g

accordance with American Dental Association specification No. 8. Mixing time for each cement was 1.5 minutes. At two minutes the cement was loaded into the orthodontic band. Thirty seconds were allowed to load the band and seat it in place with hand pressure. The cement was left undisturbed for 15 minutes to assure adequate set. At the end of this period the specimen was hand scaled to remove all excess cement and then immersed in room temperature water for 24 hours. Only one band was cemented with each cement mix. Cementation order of the three cements was randomized.

A tensile testing instrument* was employed to test the force necessary to remove the cemented orthodontic bands from the specimen teeth. The tooth, embedded in the acrylic block, was clamped into the superior vise grip of the instrument. The superior vise grip consisted in part of a swivel joint which allowed lateral and rotational movement. A wire and rod apparatus was attached to the inferior vise grip (Fig. 2). This apparatus consisted of two 0.20 inch wires for looping over the tie buttons on the orthodontic bands, a steel rod of 0.375 inch diameter for vertical compensation, and a 0.062 inch wire for attachment to the

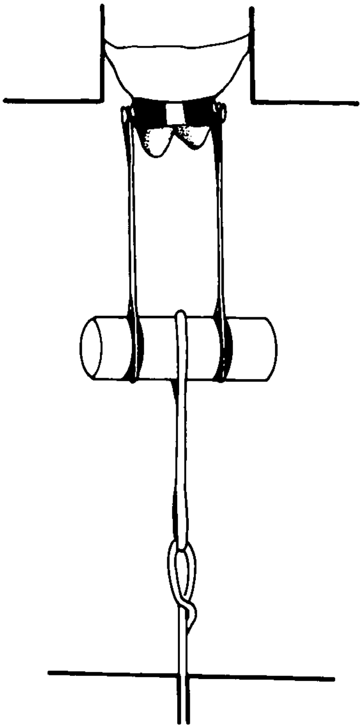

Fig. 2 Illustration of wire and rod apparatus for testing the retentive strengths of orthodontic cements.

inferior vise grip. Shallow grooves were placed in the rod, one at either end and one in the center. These grooves prevented the wires from sliding along the rod. Such an arrangement allowed the rod to freely rotate about its center point to compensate for any vertical discrepancy in the button attachment height and for self-alignment of the apparatus whenever it was placed under tension. All forces were directed parallel to the long axis of the tooth during band removal. Crosshead speed for band removal was 0.02cm/min with a graph speed of 2.0cm/min. The maximum retentive strength or cement failure was interpreted from the stress-strain curves as that point at which linearity was interrupted.

After each experimental trial the teeth were hand scaled and lightly polished with pumice and stored in water.

*Instron Testing Machine, Instron Corporation, Canton, Massachusetts.

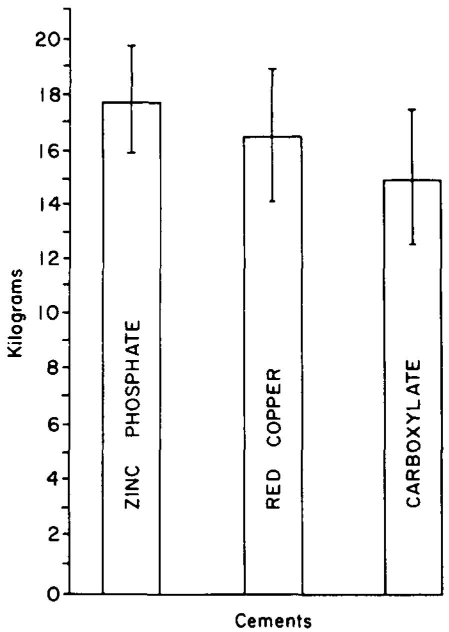

Fig. 3 Mean retentive value required to dislodge orthodontic bands cemented with zinc phosphate, red copper, and carboxylate cements. Error bars denote ± one standard deviation of the mean.

A new orthodontic band was fitted for each experimental trial. A total of 150 cement trials were run during the investigation. Fifty cement trials were performed with each of the three cements tested. The data were analyzed using the standard measures of central tendency and a two-way analysis of variance. The three cements were considered as a fixed factor and teeth a random factor.

Results

The mean retentive values of the three cements evaluated are illustrated in Figure 3. Each bar or column represents the mean value of fifty tests. Mean retentive values for the three cements were 17.9 kilograms for zinc phosphate, 16.6 kilograms for red copper, and 15.0 kilograms for the carboxylate cement. Standard deviation values in kilograms are indicated by error bars. A two-way analysis of variance was used to treat the data. The usual estimates of the effects in this type of model are displayed in an ANOVA table (Table II).

The analysis of variance revealed that there was a significant difference between the three cements ($p = 0.033$). Since this gives no indication of where the differences lie, a multiple comparison technique due to Tukey[13] was used to make further comparisons between the three cements. This statistical analysis revealed that there was no significant difference between the retentive value of zinc phosphate cement versus red copper cement, nor was there a

TABLE II

ANOVA table; a two way analysis of variance of retentive data with cements as a fixed factor and teeth as a random factor

Source	*Degrees of Freedom* df	*Sum of Squares* ss	*Mean Square* ss/df	*F Ratio*	*P Value*
Teeth	9	491.69	54.632	$\frac{54.632}{5.1014} = 10.7092^*$	$p < .001$
Cements	2	203.53	101.76	$\frac{101.76}{24.593} = 4.1378^*$	$p = .033$
Teeth and Cement	18	442.67	24.593	$\frac{24.593}{5.1014} = 4.8208^*$	$p < .001$
Residual Error	120	612.16	5.1014		
Total	149				

* significant at 0.95 level

significant difference between the retentive value of red copper cement as compared with carboxylate cement. However, there was a significant difference between the retention provided by zinc phosphate cement as compared with carboxylate cement at the 0.95 level of confidence with the zinc phosphate cement giving superior retention.

Figure 4 represents the mean retentive strengths of all three cements for each tooth cemented and tested. Each data point represents the average of five tests. All 150 tests were carried out in a randomized sequence. It is apparent from the plotted data that no trend existed between retentive strengths and the number of times a tooth was cemented and tested.

Visual examination of the orthodontic bands and teeth immediately after testing revealed that all three cements generally adhered to the tooth surface more so than they did to the metal band. Although somewhat unexpected, the adhesion of the carboxylate cement to the band was subjectively noted to be no greater than that of the other two cements.

Discussion

This investigation combined the retention testing procedures from several other studies to provide a clinically useful test of orthodontic cementing agents. It must be noted, however, that absolute retention cannot be measured directly. To do so one must take into account such factors as the oral environment and the complex forces brought to bear on the orthodontic appliances. Nonetheless, the tensile testing procedure employed in this study provides an adequate method for screening various luting agents for clinical usage. In addition, this system makes it possible to conveniently measure the relative retentive strengths of various cements.

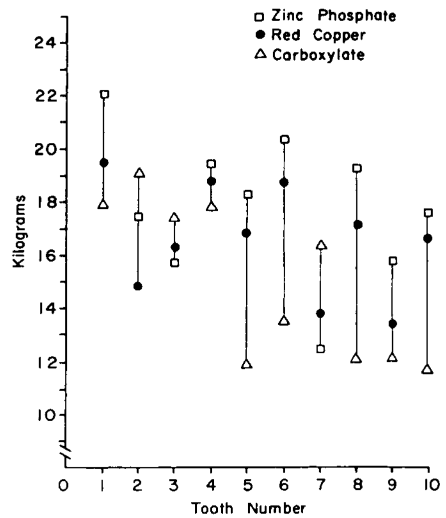

Fig. 4 Mean retentive strengths of the three cements for each tooth cemented and tested. Each data point represents the average of five tests.

In determining retention, a specific property of the cement was measured and then used as a definition or measure of retention. In this case the strength required to initially fracture the cement bond holding the orthodontic bands to the specimen tooth was used as the measure of cement retention. This was usually not the maximum strength required to unseat the orthodontic band from the tooth, since after the initial breakage of the cement bond the band would deform and start to peel off the tooth. This initial fracture point of the cement was relatively easy to identify due to the continuous graphic readout and extreme sensitivity of the tensile testing instrument used in the study.

The reliability of the testing methodology proved to be quite satisfactory. As can be seen in Figure 3, the coefficient of variation of the cement retentive values averaged about 12% which indicates an improvement in reliability compared with 26% reported by earlier investigators.[10] The low coefficient of variation of this investigation was a result of several factors including the design of the band removal apparatus, careful cement manipulation, the randomization of cementation order, and the careful control of variables inherent in the methodology using extracted human teeth and orthodontic bands.[15]

In examining the experimental results, Figure 4 reveals no consistent pattern of increase or decrease of retentive values for a single tooth. This indicates that etching of the enamel by the cement was not a significant factor affecting retentive values during the investigation. These findings are in agreement with previous studies[10,14] in which no etching of the enamel surface after repeated *in vitro* cementations of orthodontic bands was observed.

The mean retentive value for each cement on each tooth indicates there is a nonparallelism of cement retentive values between the different teeth (Fig. 4). For example, zinc phosphate cement possessed the highest retentive value on tooth one, but on tooth two it had only the second highest value, and on tooth three it had the lowest value. These figures suggest that certain cements perform better on certain teeth than on others. Zinc phosphate cement and red copper cement show an almost complete parallel relationship except for two points where the retentive value for red copper was greater than for zinc phosphate. It would be expected that these two cements perform in a similar manner because red copper is almost identical to zinc phosphate except for a small percentage of cuprous oxide added to the zinc oxide powder. The liquid portion of the two cements is essentially identical.

Carboxylate cements performed in a nonparallel manner compared with zinc phosphate and red copper cements. This was probably due to the nature of the bond between the carboxylate cement and the tooth enamel. While zinc phosphate and red copper cements achieve their retention by a pure mechanical lock between the cement and microscopic irregularities on the tooth surface, carboxylate cement achieves a chemical bond between the cement and the enamel.[3]

It has been suggested that the bond strength of carboxylate cement is decreased by an irregular enamel surface.[4] This means that on a tooth with a smooth enamel microsurface the carboxylate cement may perhaps bond more strongly than it would on a rough enamel microsurface. The opposite would be true for zinc phosphate and red copper cements. They would bond more strongly to a rough enamel surface than to a smooth one. This could be an explanation of why the carboxylate cement performed better on some teeth than the other cements. This would also account for the fact that when the mean retentive values of zinc phosphate and red copper decreased, the mean retentive values of carboxylate cement increased.

In examining Table II, the ANOVA table, three significant facts can be seen. First, there was a significant difference between teeth ($p < 0.001$). This is to be expected since the sample was selected from an infinite variety, size, surface texture, and surface contour of premolar teeth. Secondly, there was a significant interaction between teeth and cement ($p < 0.001$). From the observations made concerning Figure 4, most of the interaction was due to the carboxylate cement and not to the zinc phosphate or red copper cement. The carboxylate cement to tooth interaction suggests a different mechanism of bonding as compared with the other two cements. Thirdly, there was a significant difference among the three cements ($p = 0.033$).

Carboxylate cement proved to provide the least retentive strength of the cements investigated. This was surprising since carboxylate cement was the most difficult to scale from the specimen tooth following cementation. This may give rise to the impression among many clinicians that carboxylate cement provides superior retention over other cement types, an impression the present investigation quite clearly shows to be inaccurate. It should be emphasized, however, that this pertains only to retention of orthodontic bands, not necessarily to retention of a button or bracket attached to a partially impacted tooth.

Summary and Conclusion

A reliable method for testing the retentive strength of orthodontic cements was developed. Orthodontic bands were cemented to extracted human premolar teeth with three different types of proprietary dental cements. The strength necessary to remove the cemented orthodontic bands was recorded with a tensile-testing instrument using a modified specimen holding device. Fifty cement trials were carried out for each of the cements for a total of 150 tests. The reliability of the testing methodology was demonstrated by the low coefficient of variation which averaged 12 per cent.

For the dental cements included in the investigation, zinc phosphate cement was found to have the highest retentive value followed by red copper and lastly, by carboxylate cement. Statistical analysis revealed that there was no significant difference between the retentive value of zinc phosphate and red copper cement. There was a significant difference between the retention provided by zinc phosphate cement when compared with carboxylate cement at the 0.95 level of confidence.

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